analysis a typical LEO altitude of 400 km is assumed and again a 72° inclination is considered which causes the satellite to pass over the entire CONUS numerous times.

The interference thresholds used in the analysis are shown in Table 6-2 and are based on the conduction testing by JPL last March. Although anechoic chamber testing and live-sky testing have also been performed with these receivers, the conduction testing offers the best accuracy since signal, noise, and interference levels can be carefully controlled and calibrated. In the conduction testing, the primary observable was the degradation in C/No due to simulated LightSquared Phase 1 signal interference (two 5 MHz channels) measured during steady state tracking. (It should be noted, however, that JPL also collected pseudorange, carrier phase, and position solution data. They also collected data for the TRIG using a Phase 0 simulated LightSquared signal.) Table 6-2 shows the interference levels (sum of interference powers in both 5 MHz channels) at the output of the GPS receiver antenna that result in 1 dB, 3 dB, and 5 dB C/No degradation for the four NASA receivers along with the interference level that causes loss of GPS signal tracking. It's apparent that the next-generation TRIG space receiver is the most sensitive of the four receivers.

Terrestrial Receiver Analysis (single base station)

This analysis considers the impact of interference from a single LightSquared base station on the four receivers assuming they are located at fixed positions on the ground. The TRIG/IGOR space receivers are tested on the ground prior to launch and during "burn-in" operations. Receivers #15 & #16 are commonly used in surveying and high precision ground networks such as the IGS (Figure 6-6 and Figure 6-6) and SCIGN (Figure 6-8 and Figure 6-9). Receiver #16 is a standard dual frequency (L1/L2) phase and pseudorange measuring instrument that can track up to 12 GPS satellites. Receiver #15 is a newer 36-channel receiver capable of tracking GPS L1/L2/L2C/L5 and GLONASS L1/L2. Since the closest base station will dominate the aggregate interference, it's useful to estimate the required separation distance between GPS receiver and base station in order that certain interference threshold levels are not exceeded. For this analysis the GPS receiver is assumed to be 1 meter above the ground (e.g. tripod mounted) with a zenith pointed choke ring antenna with gain pattern shown in Figure 6-3. This antenna is designed specifically to reduce multipath effects and consists of vertically aligned concentric rings centered about the antenna element (usually a crossed dipole) connected to a ground plane. The vertical rings shape the antenna pattern such that multipath signals incident on the antenna at the horizon and negative elevation angles are attenuated. The separation distance contours were calculated with MathCAD software for different interference thresholds given in Table 6-2.

Terrestrial Receiver Analysis (multiple base stations)

This analysis considered aggregate interference from the LightSquared deployment in one of LightSquared's planned initial markets. LightSquared provided the locations and height above ground for base stations that it is planning to deploy in one of its initial market areas. The objective is to determine the interference impact to a high precision ground network GPS receiver if it were to be located at different positions in the area (or a similar LightSquared market area). Again the receivers are assumed to use zenith pointed choke ring antennas at 1 meter above ground. For this analysis a MATLAB program was developed which sub-divides the geographic area into a large number of quadrangles or cells (i.e. 878,628 cells each approx 100 square meters in size) and the aggregate interference calculated at the centroid of each map cell from the base stations within radio LOS of the map cell location. The result is an interference matrix map that shows the aggregate interference over the geographic area. By applying different interference thresholds (Table 6-2) to the matrix map, the % area where interference exceeds the threshold can be determined.

LightSquared Base Station Characteristics

As shown in Table 6-1, for all three analysis types, base station sector main-beam EIRP levels and antenna patterns are the same and based on data provided by LightSquared. The main-beam EIRP per channel is 62 dBm (32 dBW) per (5 MHz) OFDM channel and assuming two 5 MHz channels per sector (i.e. Phase 1 spectrum) this is 65 dBm (35 dBW) per sector.

Spaceborne Receiver Analysis

For the spaceborne receiver analysis the aggregate interference power at the output of the GPS receiver antenna is calculated at one second time steps in the satellite orbit from base stations distributed among certain US cities. Since specific lat/lon locations for the base stations in each city were not available and the GPS receiver in this case is onboard a satellite, it was assumed for the interference calculations that all base stations for a particular city are co-located at the city center. For example, two base stations separated by 10 km will have an angular separation of only 0.7° at 800 km satellite altitude so that the difference in receive antenna gain between the two will be very small. Sector antenna gain towards the satellite is calculated by first determining the appropriate AZ/EL angles from the base-station/satellite geometry; then summing the AZ plane discrimination with the EL plane discrimination; and then subtracting this total discrimination from the max sector gain to get the net sector gain towards the satellite. The maximum interference from a base station will occur when it sees the satellite at low elevation angles. Free-space loss is assumed, but because of uncertainty in the path loss due to blockage and shadowing of base stations on the satellite horizon from terrain or man-made structures, analysis results were generated for two base station mask angles: (1) a 0° elevation mask on the base stations so that all base stations which see the satellite above 0° elevation angle are included in the aggregate interference calculation; and (2) a 5° mask angle so that only base stations which see the satellite above 5° elevation angle contribute to the aggregate interference. For the space receiver analysis, results were also generated for the case when the base station EIRP is increased from 32 dBW to 42 dBW, which is the maximum authorized power under the FCC rules. LightSquared, however, has stated that they plan to operate at a maximum EIRP level of 32 dBW per channel.

Terrestrial Receiver Analysis (single base station)

For this analysis of interference from single base station, a base station height of 18.3 meters (60 feet) above ground is assumed. GPS receiver height is assumed to be 1 meter. Separation distance results were calculated for a number of different propagation models besides free-space loss (i.e. Hata, Extended Hata, Walfisch-Ikegami, NTIA/ITM). These models are based on extensive measurements of radio propagation losses and used in cellular systems planning. Figure 6-5 shows that there is a significant spread in path loss among these models. For example, for a 10 km distance path loss varies from 115 dB (free-space) to 180 dB (extended HATA in urban area). This leads to a significant difference in separation distances. The issue of which propagation model is appropriate in various terrestrial interference scenarios requires further discussion.

Terrestrial Receiver Analysis (multiple base stations)

As noted previously, this analysis considers aggregate interference from base stations in one of LightSquared's initial market deployments. Again results were generated for different propagation models shown in Figure 6-5.

Analysis Results

(*Editor's Note:* The results presented in the following sections are intended to draw no conclusions or make any recommendations as to what level of interference may be tolerated by the various GPS receivers based on the scenarios for those receivers.)

Spaceborne Receiver Analysis Results

Interference results for the RO GPS RX onboard a COSMIC-2 satellite (800 km/72° orbit) are shown in Table 6-3 and Table 6-4. Table 6-3 assumes a 0° elevation mask on the base stations while Table 6-4 assumes a 5° elevation mask on the base stations. The entries in these tables are interpreted as follows. Consider, for example, Table 6-3 and an aggregate interference threshold of -82 dBm (2nd column). For this row in the Table, the first column indicates that an interference power level of -82 dBm at the output of the GPS receiver antenna will cause a 1 dB drop in the C/No for the TRIG receiver (for both the L1 C/A-code and L1 P-code channels of the receiver). Column 3 indicates that over the 10-day simulation period, the aggregate interference at the GPS antenna output actually exceeds this level about 9% of the time (i.e. since 10 days = 240 hours, the interference exceeds -82 dBm for 0.09 x 240 = 21.6 hours total over the 10-day period). In other words, for 9% of the time, the receiver C/No degradation is at least 1 dB. In the table header, the peak interference level is shown to reach -55.1 dBm (enough for the TRIG to lose lock). Column 4 indicates that over the 10-day period, there are 268 interference events (i.e. 268 separate time intervals during which interference exceeds -82 dBm). Note that these time intervals may be very short or fairly long depending on how many interfering base stations the satellite sees on the particular orbit pass over the US. The sum duration of all 268 interference events is the 21.6 hours. Also, there can be multiple interference events for a single orbit pass as different numbers of base stations pass through the FOV of the receiver antenna. Column 5 indicates that the average duration of an interference event is about 4.9 minutes and the maximum duration from column 6 is 16.9 minutes. Table 6-3 also shows that for a threshold of -67 dBm (where TRIG loses lock), interference exceeds this level about 3% of the time with 152 interference events of average duration 2.9 min and max duration 10.6 min. It should be noted that the duration of an atmospheric occultation (as the signal path moves from skimming the Earth's surface to an altitude of about 100 km) is only one to two minutes. Table 6-4 with the 5° elevation mask ignores interference from the low elevation angle base stations, but still shows average interference event duration of 3.8 min at the -67 dBm TRIG loss of lock threshold. (Compared to Table 6-3 there are fewer events, 57 vs 152, but the average duration is longer.)

The impact to the IGOR space receiver is seen to be much less. Note, however, that these results are only for the forward looking RO antenna. There will also be an aft pointing RO antenna, so interference will occur both when the CONUS is coming into the forward looking antenna FOV and when it is leaving the aft looking antenna FOV. Further analysis is required to determine the interference statistics when both antennas are included.

For the case of RO receiver onboard COSMIC-2 satellite in the 520 km/24° inclined orbit, the peak interference was found to be -88.2 dBm. This is much lower than for the 800 km/72° inclined orbit since the satellite does not pass over the US, but only sees a few base stations on the southern border. This level of interference is expected to cause less than 1 dB of degradation to the TRIG receiver.

Interference results for the navigation mode GPS RX with zenith pointed antenna onboard a LEOSAT (400 km/72° orbit) are shown in Table 6-5 (0° base station elevation mask) and Table 6-6 (5° base station elevation mask). The majority of GPS receivers used in space are small, lightweight, low-power devices providing spacecraft 3-dimensional position and velocity as well as timing and possibly 3-axis attitude determination. Table 6-5 and Table 6-6 show that compared to the RO case, interference effects are much less due to the backlobes and sidelobes of the receiving antenna facing towards the earth (and interfering base stations). Note also that no satellite body masking is included in this case which will likely further reduce the interference.

Although LightSquared is planning to operate the base stations at a maximum EIRP of 32 dBW per channel, the current FCC rules allow them to operate up to 42 dBW EIRP. Table 6-7, Table 6-8, Table 6-9, and Table 6-10 show the interference results if the base stations were to operate at 42 dBW EIRP.

Terrestrial Receiver (single base station) Analysis Results

Separation distance contours for the four receivers are shown in Figure 6-10 through Figure 6-13. In these polar plots, the base station is assumed to be at the center of the plot with the 3 sector antennas oriented in the 0°, 120°, and 240° azimuth directions. The radial rings show distance from the center (base station) in km. Contours are shown for several different propagation models. The least conservative models are shown on the left side and the most conservative on the right side. Note the different distance scales on the plots. In each case, the contours are associated with the receiver interference threshold that causes 1 dB C/No drop in the C/A-code channel. Referring to Table 6-2, these thresholds are -82 dBm (TRIG); -57 dBm (IGOR); -54 dBm (Receiver #15); and -68 dBm (Receiver #16). Base station height is 18.3 meters and GPS rx height is 1 meter. For these heights the radio LOS distance is 22 km so a receiver beyond 22 km is assumed not to receive interference. There is large variation in required separation distance depending on the assumed propagation model. Free-space loss yields the largest (most protective) separation distances: 22 km (TRIG); 4 km (IGOR); 3 km (Receiver #15); and 14 km (Receiver #16).

Terrestrial Receiver (multiple base station) Analysis Results

The results of this analysis are shown in Table 6-11 (redacted due to competitive sensitive data).

Table 6-1. NASA GPS Receiver Analysis Assumptions

		SPACEBORNE RECEIVER ANALYSIS	TERRESTRIAL RECEIVER ANALYSIS (SINGLE LSQ BASE STATION)	TERRESTRIAL RECEIVER ANALYSIS (MULTIPLE LSQ BASE STATIONS)
GPS CHARACTERISTICS	COMPUTATION METHOD	MATLAB TIME SIMULATION TO COMPUTE AGG INTERFERENCE FROM CONUS BASE STATIONS INTO ORBITING GPS RX (10-DAY SIM PERIOD @ 1-SEC TIME STEP)	MATHCAD CALCULATION USED TO COMPUTE REQUIRED SEPARATION DISTANCE CONTOURS FROM SINGLE BASE STATION	MATLAB INTERFERENCE MATRIX MAP COMPUTATION TO DETERMINE AGG LEVEL OF INTERFERENCE FROM MULTIPLE BASE STATIONS IN LAS VEGAS DEPLOYMENT
	GPS RX TYPE (all dual-frequency semi-codeless)	TRIG (next-gen space/occulation rx); IGOR (current gen space/occulation rx)	TRIG; IGOR; JAVAD; ASHTECH	JAVAD; ASHTECH
	ORBIT	COSMIC 2 HI ALT (800 km/72°) (FIG 1) COSMIC 2 LO ALT (520 km/24°) GENERIC LEO (400 km/72°)	N/A	N/A
	GPS RX ANTENNA TYPE	OCCULT 12-ELEMENT ARRAY (15.2 dBic for COSMIC-2 ORBITS) (FIG 2); CHOKE RING (6.8 dBic for GENERIC LEO) (FIG 3)	CHOKE RING (6.8 dBic) (FIG 3)	CHOKE RING (6.8 dBic) (FIG 3)
	GPS RX ANTENNA POINTING	TOWARDS EARTH LIMB (COSMIC-2 OCCULT ORBITS); ZENITH (GENERIC LEO)	ZENITH POINTED	ZENITH POINTED
	GPS RX ANTENNA PATTERN	OCCULT 12-ELEMENT ARRAY; CHOKE RING	CHOKE RING	CHOKE RING
	INTERFERENCE THRESHOLD	THRESHOLDS AS MEASURED DURING JPL CONDUCTED TESTING (TABLE 2)	THRESHOLDS AS MEASURED DURING JPL CONDUCTED TESTING (TABLE 2)	THRESHOLDS AS MEASURED DURING JPL CONDUCTED TESTING (TABLE 2)
	POLARIZATION LOSS	3 DB	3 DB	3 DB
LIGHTSQUARED BASE STATION CHARACTERISTICS	DEPLOYMENT	Redacted for Commercial Sensitivitv Reasons		
	SPECTRUM PHASE	PHASE 1: TWO (5 MHz) CHANNELS	PHASE 1: TWO (5 MHz) CHANNELS	PHASE 1: TWO (5 MHz) CHANNELS
	CHANNEL FREQS	1526.3 - 1531.3 MHz/ 1550.2 - 1555.2 MHz	1526.3 - 1531.3 MHz/ 1550.2 - 1555.2 MHz	1526.3 - 1531.3 MHz/ 1550.2 - 1555.2 MHz
	EIRP/CHANNEL STRUCTURE	62 dBm per (5 MHz) channel	62 dBm per (5 MHz) channel	62 dBm per (5 MHz) channel
	CHANNELS PER SECTOR	2 (PHASE 1)	2 (PHASE 1)	2 (PHASE 1)
	EIRP per SECTOR	65 dBm	65 dBm	65 dBm
	SECTORS per BASE STATION	Redacted for Commercial Sensitivity Reasons		
	SECTOR ANTENNA PATTERN			
	PROPAGATION MODEL	Redacted	RESULTS GENERATED FOR VARIOUS PROP MODELS (FREE-SPACE, HATA, EXTENDED HATA, Walfisch-Ikegami, NTIA/ITM) (FIG 6)	RESULTS GENERATED FOR VARIOUS PROP MODELS (FREE-SPACE, HATA, EXTENDED HATA, Walfisch-Ikegami, NTIA/ITM) (FIG 6)

Table 6-2. Summary of JPL Conduction Testing Interference Thresholds

		NASA GPS RECEIVER SUSCEPTIBILITY TO LSQ INTERFERENCE (BASED ON JPL CONDUCTED TESTING)											
		NOTE: POWER LEVEL SHOWN IS TOTAL POWER AT OUTPUT OF GPS RX PASSIVE ANTENNA (dBm)											
LSQ Signal Spectrum	Interference Criterion	TRIG			IGOR			JAVAD Delta G3T			Ashtech Z-12		
		L1 C/A	L1 P	L2 P	L1 C/A	L1 P	L2 P	L1 C/A	L1 P	L2 P	L1 C/A	L1 P	L2 P
LSQ Phase 1 (two 5 MHz channels @ 1526.3-1531.3 and 1550.2-1555.2)	1 dB C/No degradation	C: -82	C: -82	C: -78	C: -57	C: -59	C: -53	C: -54	C: -56	C: -43	C:68		
	3 dB C/No degradation	C: -78	C: -80	C: -77	C: -53	C: -54	C: -49	C: -51	C: -52	C: -43	C:65		
	5 dB C/No degradation	C: -75	C: -73	C: -74	C: -49	C: -51	C: -48	C: -49	C: -50	C: -43	C:62		
	Loss of Lock	C: -67	C:-67	C: -67	C: -45	C: -45	C: -45	C: -43	C: -43	C: -43	C: -38	C: -38	C: -38

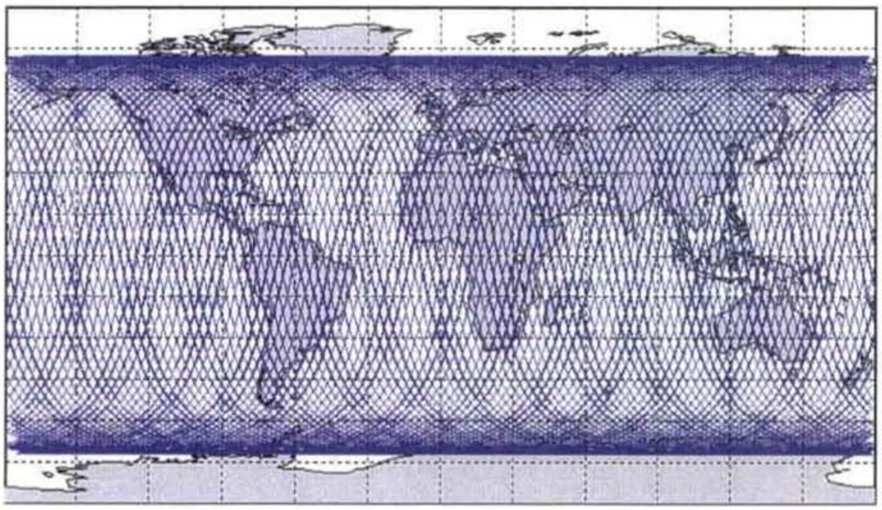


Figure 6-1. Ground Track of COSMIC-2 Satellite in 800 km/72° Orbit over 10-Day Sim Period

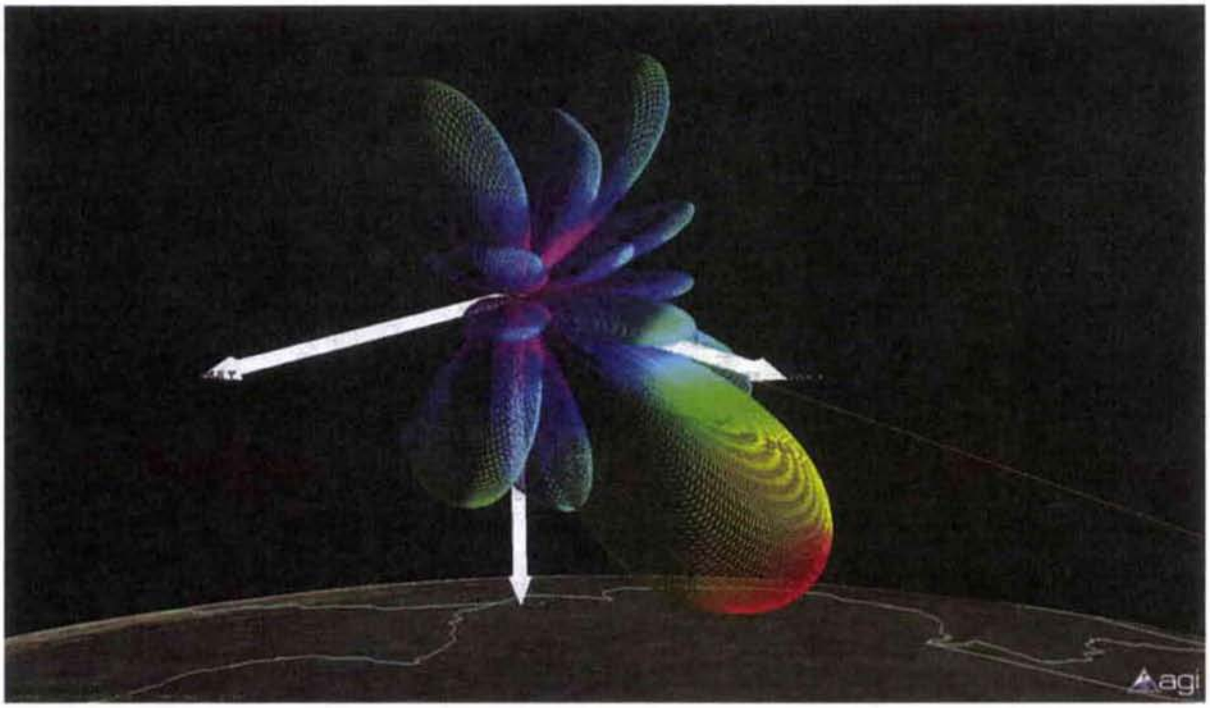
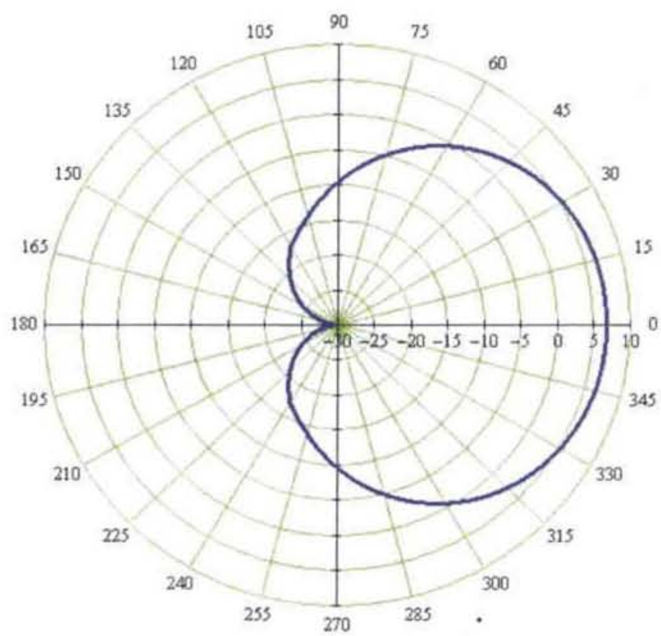


Figure 6-2. Gain Pattern of JPL GPS RX Occultation Antenna (12-element array with 15.2 dBic main beam pointed towards Earth limb)



Off-boresight Angle (deg) θ =	Gain (dBic) Choke_Ring2(θ)
0	6.7537
5	6.7081
10	6.5967
15	6.4016
20	6.1077
25	5.7031
30	5.1787
35	4.5286
40	3.7497
45	2.8421
50	1.8087
55	0.6556
60	-0.6083
65	-1.9709
70	-3.4173
75	-4.9294
80	-6.4863
85	-8.0639
90	-9.6353

Figure 6-3. GPS Receiver Choke Ring Gain Pattern (6.75 dBic gain)

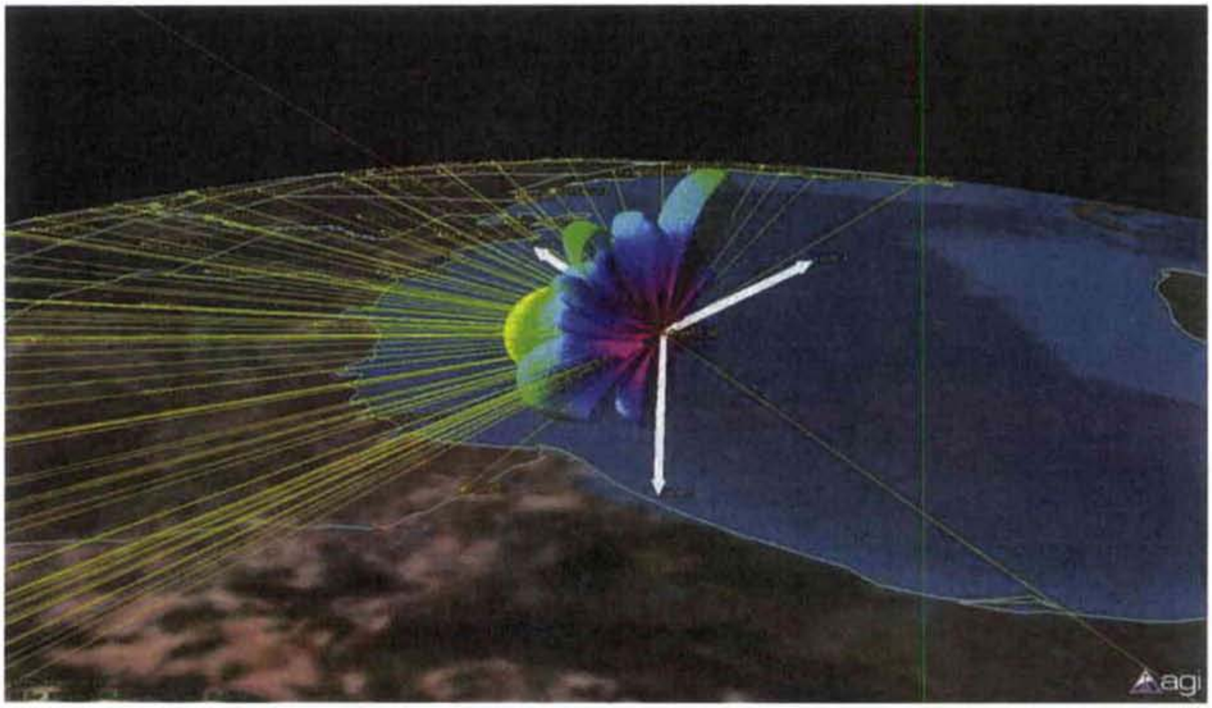


Figure 6-4. Spaceborne GPS RX Occultation Scenario (Main beam of Array Antenna is Pointed 26.2° Below the Satellite Local Horizontal Towards the Earth Limb)

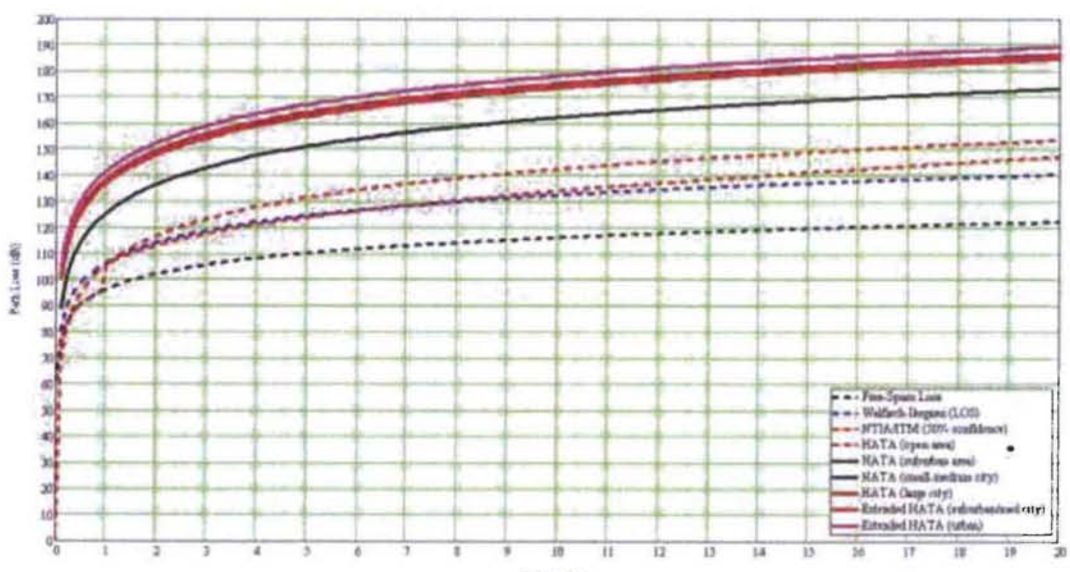


Figure 6-5. Comparison of Various Terrestrial Propagation Models

Figure 6-6. Locations of GPS Receivers of the International GNSS Service (IGS). There are 58 receivers in CONUS. The IGS collects, archives, and distributes GPS data for a wide range of applications and experiments (e.g. earth rotation, ionospheric maps, GPS/GLONASS ephemeris).

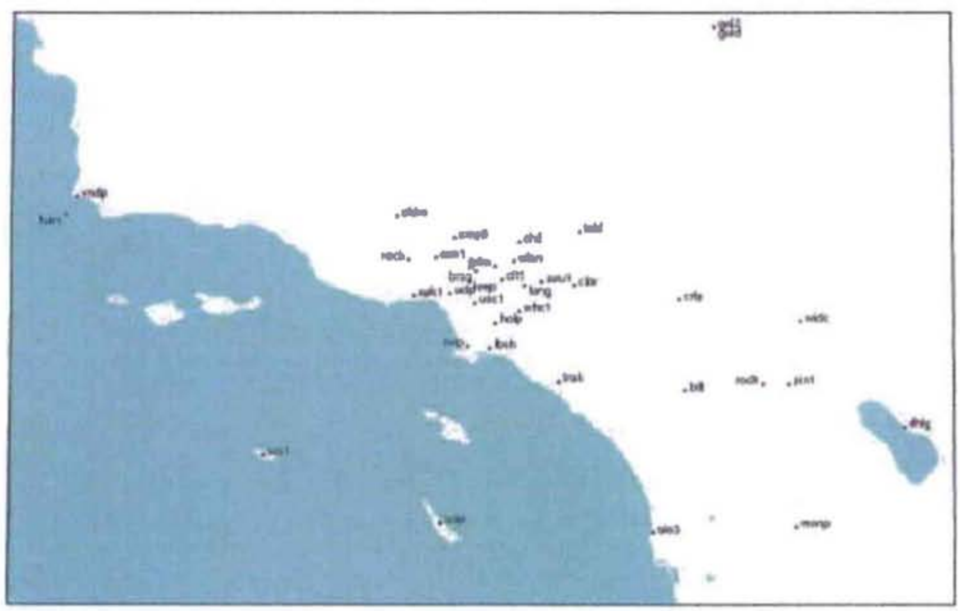


Figure 6-7. IGS Receivers in Sothern California Area

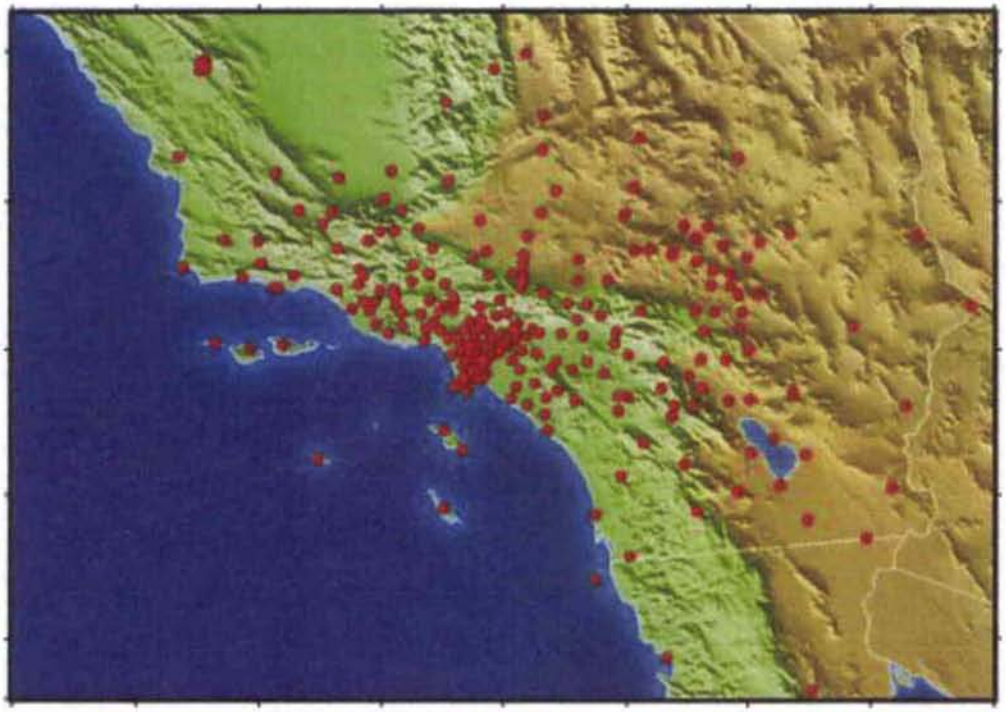


Figure 6-8. Locations of the 123 GPS Receivers of the SCIGN (Southern California Integrated GPS Network. The network continuously records mm-scale movements of the Earth's crust to estimate earthquake hazard)

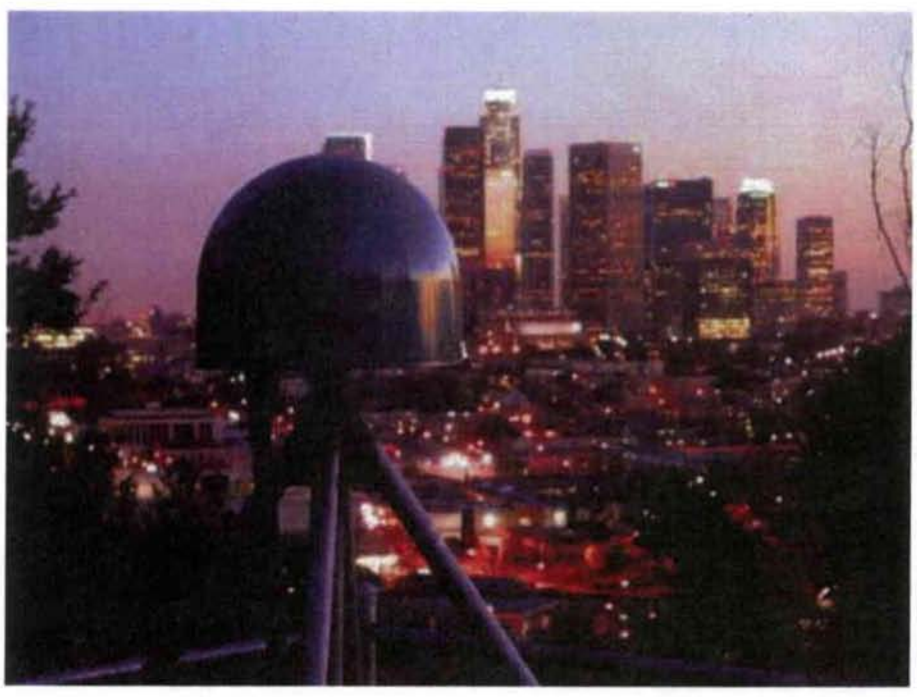


Figure 6-9. Packard SCIGN Station (located in Elysian Park above downtown L.A.)

Table 6-3. Interference Results for JPL Occultation GPS RX Onboard COSMIC-2 Satellite (800 km/72° orbit) With Earth Limb Pointed Array Antenna (0° elevation mask on base stations)

LSQ Interference Results for JPL Occultation GPS Receiver
GPS RX Onboard COSMIC-2 Satellite in 800 km/72° Orbit

Two LSQ channels per sector @ 32 dBW max EIRP per channel

0° Elevation Mask on LSQ Base Stations

Peak Interference Level = -55.1 dBm

RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold **(dBm)** (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
	-56.000	0.009	11.000	0.112	0.367
IGOR (1 dB; C/A)	**-57.000**	0.074	59.000	0.180	0.800
	-58.000	0.217	80.000	0.390	2.167
IGOR (1 dB; P1)	**-59.000**	0.384	93.000	0.595	3.533
	-60.000	0.595	86.000	0.996	5.550
	-61.000	0.829	105.000	1.137	5.767
	-62.000	1.154	136.000	1.222	6.033
	-63.000	1.531	156.000	1.413	7.617
	-64.000	1.918	157.000	1.760	8.233
	-65.000	2.297	158.000	2.094	8.900
	-66.000	2.652	165.000	2.314	9.783
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	3.033	152.000	2.873	10.600
	-68.000	3.414	157.000	3.131	10.750
	-69.000	3.787	185.000	2.948	11.483
	-70.000	4.150	153.000	3.906	11.683
	-71.000	4.477	139.000	4.638	12.017
	-72.000	4.800	145.000	4.767	12.433
TRIG (5 dB; P1)	**-73.000**	5.131	147.000	5.027	12.683
TRIG (5 dB; P2)	**-74.000**	5.452	163.000	4.817	13.350
TRIG (5 dB; C/A)	**-75.000**	5.851	193.000	4.366	13.700
	-76.000	6.262	205.000	4.399	13.917
TRIG (3 dB; P2)	**-77.000**	6.696	225.000	4.285	14.167
TRIG (3 dB; C/A) ; TRIG (1 dB; P2)	**-78.000**	7.135	240.000	4.281	15.167
	-79.000	7.601	257.000	4.259	16.117
TRIG (3 dB; P1)	**-80.000**	8.084	264.000	4.409	16.717
	-81.000	8.554	279.000	4.415	16.950
TRIG (1 dB; C/A & P1)	**-82.000**	9.059	268.000	4.867	16.983
	-83.000	9.491	258.000	5.297	17.083
	-84.000	9.878	254.000	5.600	17.150
	-85.000	10.252	266.000	5.550	17.283
	-300.000	15.749	175.000	12.960	25.300

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Table 6-4. Interference Results for JPL Occultation GPS RX Onboard COSMIC-2 Satellite (800 km/72° orbit) With Earth Limb Pointed Array Antenna (5° elevation mask on base stations)

LSQ Interference Results for JPL Occultation GPS Receiver					
GPS RX Onboard COSMIC Satellite in 800 km/72° Orbit					
Two LSQ channels per sector @ 32 dBW max EIRP per channel					
5° Elevation Mask on LSQ Base Stations					
Peak Interference Level = -60.2 dBm					
RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold **(dBm)** (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
	-56.000	0.000	0.000	0.000	0.000
IGOR (1 dB; C/A)	**-57.000**	0.000	0.000	0.000	0.000
	-58.000	0.000	0.000	0.000	0.000
IGOR (1 dB; P1)	**-59.000**	0.000	0.000	0.000	0.000
	-60.000	0.000	0.000	0.000	0.000
	-61.000	0.082	18.000	0.653	1.733
	-62.000	0.236	23.000	1.478	2.983
	-63.000	0.429	41.000	1.506	3.717
	-64.000	0.684	57.000	1.727	5.933
	-65.000	0.918	52.000	2.542	6.433
	-66.000	1.210	56.000	3.111	7.033
TRIG (Lost Lock; C/A & P1 & P2)	-67.000	1.502	57.000	3.795	7.983
	-68.000	1.817	81.000	3.230	8.150
	-69.000	2.069	76.000	3.921	8.433
	-70.000	2.355	79.000	4.292	8.917
	-71.000	2.655	75.000	5.097	9.583
	-72.000	2.994	94.000	4.586	9.850
TRIG (5 dB; P1)	-73.000	3.328	95.000	5.044	10.467
TRIG (5 dB; P2)	-74.000	3.578	94.000	5.481	11.067
TRIG (5 dB; C/A)	-75.000	3.844	110.000	5.032	11.450
	-76.000	4.113	111.000	5.335	11.533
TRIG (3 dB; P2)	-77.000	4.420	107.000	5.948	11.533
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	4.697	121.000	5.589	11.750
	-79.000	4.982	127.000	5.649	12.750
TRIG (3 dB; P1)	**-80.000**	5.275	128.000	5.934	13.217
	-81.000	5.562	121.000	6.619	13.717
TRIG (1 dB; C/A & P1)	**-82.000**	5.853	134.000	6.290	14.083
	-83.000	6.116	132.000	6.672	14.350
	-84.000	6.410	143.000	6.455	14.350
	-85.000	6.703	165.000	5.850	14.433
	-300.000	12.180	189.000	9.280	21.683

Table 6-5. Interference Results for JPL GPS RX Onboard LEOSAT (400 km/72° orbit) With Zenith Pointed Choke Ring Antenna (0° elevation mask on base stations)

LSQ Interference Results for JPL GPS Receiver with Zenith Pointed 7 dBic Choke Ring Antenna
GPS RX Onboard LEO Satellite in 400 km/72° Orbit

Two LSQ channels per sector @ 32 dBW max EIRP per channel

0° Elevation Mask on LSQ Base Stations
Peak Interference Level = -78.1 dBm

RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold (dBm) (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
	-56.000	0.000	0.000	0.000	0.000
IGOR (1 dB; C/A)	**-57.000**	0.000	0.000	0.000	0.000
	-58.000	0.000	0.000	0.000	0.000
IGOR (1 dB; P1)	**-59.000**	0.000	0.000	0.000	0.000
	-60.000	0.000	0.000	0.000	0.000
	-61.000	0.000	0.000	0.000	0.000
	-62.000	0.000	0.000	0.000	0.000
	-63.000	0.000	0.000	0.000	0.000
	-64.000	0.000	0.000	0.000	0.000
	-65.000	0.000	0.000	0.000	0.000
	-66.000	0.000	0.000	0.000	0.000
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	0.000	0.000	0.000	0.000
	-68.000	0.000	0.000	0.000	0.000
	-69.000	0.000	0.000	0.000	0.000
	-70.000	0.000	0.000	0.000	0.000
	-71.000	0.000	0.000	0.000	0.000
	-72.000	0.000	0.000	0.000	0.000
TRIG (5 dB; P1)	**-73.000**	0.000	0.000	0.000	0.000
TRIG (5 dB; P2)	**-74.000**	0.000	0.000	0.000	0.000
TRIG (5 dB; C/A)	**-75.000**	0.000	0.000	0.000	0.000
	-76.000	0.000	0.000	0.000	0.000
TRIG (3 dB; P2)	**-77.000**	0.000	0.000	0.000	0.000
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	0.000	0.000	0.000	0.000
	-79.000	0.161	80.000	0.290	1.467
TRIG (3 dB; P1)	**-80.000**	0.601	183.000	0.473	4.717
	-81.000	1.517	364.000	0.600	8.300
TRIG (1 dB; C/A & P1)	**-82.000**	2.980	322.000	1.332	11.533
	-83.000	3.915	257.000	2.193	13.067
	-84.000	4.651	290.000	2.309	13.133
	-85.000	5.387	264.000	2.938	13.983
	-300.000	15.327	165.000	13.377	25.167

Table 6-6. Interference Results for JPL GPS RX Onboard LEOSAT (400 km/72° orbit) With Zenith Pointed Choke Ring Antenna (5° elevation mask on base stations)

LSQ Interference Results for JPL GPS Receiver with Zenith Pointed 7 dBic Choke Ring Antenna
GPS RX Onboard LEO Satellite in 400 km/72° Orbit

Two LSQ channels per sector @ 32 dBW max EIRP per channel

5° Elevation Mask on LSQ Base Stations
Peak Interference Level = -81.3 dBm

RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold (dBm) (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
	-56.000	0.000	0.000	0.000	0.000
IGOR (1 dB; C/A)	-57.000	0.000	0.000	0.000	0.000
	-58.000	0.000	0.000	0.000	0.000
IGOR (1 dB; P1)	-59.000	0.000	0.000	0.000	0.000
	-60.000	0.000	0.000	0.000	0.000
	-61.000	0.000	0.000	0.000	0.000
	-62.000	0.000	0.000	0.000	0.000
	-63.000	0.000	0.000	0.000	0.000
	-64.000	0.000	0.000	0.000	0.000
	-65.000	0.000	0.000	0.000	0.000
	-66.000	0.000	0.000	0.000	0.000
TRIG (Lost Lock; C/A & P1 & P2)	-67.000	0.000	0.000	0.000	0.000
	-68.000	0.000	0.000	0.000	0.000
	-69.000	0.000	0.000	0.000	0.000
	-70.000	0.000	0.000	0.000	0.000
	-71.000	0.000	0.000	0.000	0.000
	-72.000	0.000	0.000	0.000	0.000
TRIG (5 dB; P1)	-73.000	0.000	0.000	0.000	0.000
TRIG (5 dB; P2)	-74.000	0.000	0.000	0.000	0.000
TRIG (5 dB; C/A)	-75.000	0.000	0.000	0.000	0.000
	-76.000	0.000	0.000	0.000	0.000
TRIG (3 dB; P2)	-77.000	0.000	0.000	0.000	0.000
TRIG (3 dB; C/A) TRIG (1 dB; P2)	-78.000	0.000	0.000	0.000	0.000
	-79.000	0.000	0.000	0.000	0.000
TRIG (3 dB; P1)	-80.000	0.000	0.000	0.000	0.000
	-81.000	0.000	0.000	0.000	0.000
TRIG (1 dB; C/A & P1)	-82.000	0.147	15.000	1.407	2.383
	-83.000	0.493	60.000	1.184	3.867
	-84.000	1.107	55.000	2.899	7.283
	-85.000	1.793	103.000	2.507	8.083
	-300.000	11.515	167.000	9.929	21.450

Table 6-7. Interference Results for RO GPS RX Onboard COSMIC-2 Satellite (800 km/72° orbit) With Earth Limb Pointed Array Antenna (0° elevation mask on base stations/42 dBW EIRP)

LSQ Interference Results for JPL Occultation GPS Receiver					
GPS RX Onboard COSMIC Satellite in 800 km/72° Orbit					
Two LSQ channels per sector @ 42 dBW max EIRP per channel					
0° Elevation Mask on LSQ Base Stations					
Peak Interference Level = -45.1 dBm					
RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold **(dBm)** (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
IGOR (Lost Lock)	**-46.000**	0.009	11.000	0.112	0.367
	-47.000	0.074	59.000	0.180	0.800
IGOR (5dB;P2)	**-48.000**	0.217	80.000	0.390	2.167
IGOR (5 dB; C/A)	**-49.000**	0.384	93.000	0.595	3.533
	-50.000	0.595	86.000	0.996	5.550
IGOR (1 dB; P2) IGOR(5dB;P1)	**-51.000**	0.829	105.000	1.137	5.767
	-52.000	1.154	136.000	1.222	6.033
IGOR (3 dB; C/A)	**-53.000**	1.531	156.000	1.413	7.617
IGOR (3dB; P1)	**-54.000**	1.918	157.000	1.760	8.233
	-55.000	2.297	158.000	2.094	8.900
	-56.000	2.652	165.000	2.314	9.783
IGOR (1 dB; C/A)	**-57.000**	3.033	152.000	2.873	10.600
	-58.000	3.414	157.000	3.131	10.750
IGOR (1 dB; P1)	**-59.000**	3.787	185.000	2.948	11.483
	-60.000	4.150	153.000	3.906	11.683
	-61.000	4.477	139.000	4.638	12.017
	-62.000	4.800	145.000	4.767	12.433
	-63.000	5.131	147.000	5.027	12.683
	-64.000	5.452	163.000	4.817	13.350
	-65.000	5.851	193.000	4.366	13.700
	-66.000	6.262	205.000	4.399	13.917
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	6.696	225.000	4.285	14.167
	-68.000	7.135	240.000	4.281	15.167
	-69.000	7.601	257.000	4.259	16.117
	-70.000	8.084	264.000	4.409	16.717
	-71.000	8.554	279.000	4.415	16.950
	-72.000	9.059	268.000	4.867	16.983
TRIG (5 dB; P1)	**-73.000**	9.491	258.000	5.297	17.083
TRIG (5 dB; P2)	**-74.000**	9.878	254.000	5.600	17.150
TRIG (5 dB; C/A)	**-75.000**	10.252	266.000	5.550	17.283
	-76.000	10.624	247.000	6.194	17.600
TRIG (3 dB; P2)	**-77.000**	10.978	243.000	6.506	17.733
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	11.325	244.000	6.683	17.733
	-79.000	11.647	244.000	6.874	17.750
TRIG (3 dB; P1)	**-80.000**	11.912	239.000	7.177	17.783
	-81.000	12.170	258.000	6.793	17.983
TRIG (1 dB; C/A & P1)	-82.000	12.459	257.000	6.981	19.033
	-83.000	12.712	258.000	7.095	19.033
	-84.000	12.985	259.000	7.219	20.067
	-85.000	13.269	255.000	7.493	20.067
	-300.000	15.749	175.000	12.960	25.300

Table 6-8. Interference Results for RO GPS RX Onboard COSMIC-2 Satellite (800 km/72° orbit) With Earth Limb Pointed Array Antenna (5° elevation mask on base stations/42 dBW EIRP)

LSQ Interference Results for JPL Occultation GPS Receiver					
GPS RX Onboard COSMIC Satellite in 800 km/72° Orbit					
Two LSQ channels per sector @ 42 dBW max EIRP per channel					
5° Elevation Mask on LSQ Base Stations					
Peak Interference Level = -50.2 dBm					
RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold (**dBm**) (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
IGOR (Lost Lock)	**-46.000**	0.000	0.000	0.000	0.000
	-47.000	0.000	0.000	0.000	0.000
IGOR (5dB;P2)	**-48.000**	0.000	0.000	0.000	0.000
IGOR (5 dB; C/A)	**-49.000**	0.000	0.000	0.000	0.000
	-50.000	0.000	0.000	0.000	0.000
IGOR (1 dB; P2) IGOR(5dB;P1)	**-51.000**	0.082	18.000	0.653	1.733
	-52.000	0.236	23.000	1.478	2.983
IGOR (3 dB; C/A)	**-53.000**	0.429	41.000	1.506	3.717
IGOR (3dB; P1)	**-54.000**	0.684	57.000	1.727	5.933
	-55.000	0.918	52.000	2.542	6.433
	-56.000	1.210	56.000	3.111	7.033
IGOR (1 dB; C/A)	**-57.000**	1.502	57.000	3.795	7.983
	-58.000	1.817	81.000	3.230	8.150
IGOR (1 dB; P1)	**-59.000**	2.069	76.000	3.921	8.433
	-60.000	2.355	79.000	4.292	8.917
	-61.000	2.655	75.000	5.097	9.583
	-62.000	2.994	94.000	4.586	9.850
	-63.000	3.328	95.000	5.044	10.467
	-64.000	3.578	94.000	5.481	11.067
	-65.000	3.844	110.000	5.032	11.450
	-66.000	4.113	111.000	5.335	11.533
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	4.420	107.000	5.948	11.533
	-68.000	4.697	121.000	5.589	11.750
	-69.000	4.982	127.000	5.649	12.750
	-70.000	5.275	128.000	5.934	13.217
	-71.000	5.562	121.000	6.619	13.717
	-72.000	5.853	134.000	6.290	14.083
TRIG (5 dB; P1)	**-73.000**	6.116	132.000	6.672	14.350
TRIG (5 dB; P2)	**-74.000**	6.410	143.000	6.455	14.350
TRIG (5 dB; C/A)	**-75.000**	6.703	165.000	5.850	14.433
	-76.000	7.024	174.000	5.813	14.733
TRIG (3 dB; P2)	**-77.000**	7.293	186.000	5.646	15.267
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	7.615	208.000	5.272	15.267
	-79.000	7.936	192.000	5.952	15.267
TRIG (3 dB; P1)	**-80.000**	8.217	192.000	6.163	15.433
	-81.000	8.473	200.000	6.101	15.517
TRIG (1 dB; C/A & P1)	**-82.000**	8.743	205.000	6.141	15.583
	-83.000	8.984	211.000	6.131	15.583
	-84.000	9.212	212.000	6.257	15.583
	-85.000	9.474	218.000	6.258	15.600
	-300.000	12.180	189.000	9.280	21.683

Table 6-9. Interference Results for GPS RX Onboard LEOSAT (400 km/72° orbit) With Zenith Pointed Choke Ring Antenna (0° elevation mask on base stations/42 dBW EIRP)

LSQ Interference Results for JPL GPS Receiver with Zenith Pointed 7 dBic Choke Ring Antenna					
GPS RX Onboard LEO Satellite in 400 km/72° Orbit					
Two LSQ channels per sector @ 42 dBW max EIRP per channel					
0° Elevation Mask on LSQ Base Stations					
Peak Interference Level = -68.1 dBm					
RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold **(dBm)** (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	0.000	0.000	0.000	0.000
	-68.000	0.000	0.000	0.000	0.000
	-69.000	0.161	80.000	0.290	1.467
	-70.000	0.601	183.000	0.473	4.717
	-71.000	1.517	364.000	0.600	8.300
	-72.000	2.980	322.000	1.332	11.533
TRIG (5 dB; P1)	**-73.000**	3.915	257.000	2.193	13.067
TRIG (5 dB; P2)	**-74.000**	4.651	290.000	2.309	13.133
TRIG (5 dB; C/A)	-75.000	5.387	264.000	2.938	13.983
	-76.000	6.160	297.000	2.986	14.083
TRIG (3 dB; P2)	**-77.000**	6.820	200.000	4.911	14.667
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	7.177	211.000	4.898	14.750
	-79.000	7.551	225.000	4.832	14.967
TRIG (3 dB; P1)	**-80.000**	7.974	240.000	4.785	15.650
	-81.000	8.319	210.000	5.704	17.267
TRIG (1 dB; C/A & P1)	**-82.000**	8.620	179.000	6.935	17.733
	-83.000	8.896	197.000	6.503	17.933
	-84.000	9.103	151.000	8.681	18.083
	-85.000	9.186	122.000	10.842	18.083
	-300.000	15.327	165.000	13.377	25.167

Table 6-10. Interference Results for GPS RX Onboard LEOSAT (400 km/72° orbit) With Zenith Pointed Choke Ring Antenna (5° elevation mask on base stations/42 dBW EIRP)

LSQ Interference Results for JPL GPS Receiver with Zenith Pointed 7 dBic Choke Ring Antenna					
GPS RX Onboard LEO Satellite in 400 km/72° Orbit					
Two LSQ channels per sector @ 42 dBW max EIRP per channel					
5° Elevation Mask on LSQ Base Stations					
Peak Interference Level = -71.3 dBm					
RX C/No Degradation (based on JPL conduction testing)	Agg Interference Threshold (dBm) (int power at output of GPS RX antenna)	% Time (over 10-day period) that Interference Exceeds Threshold	# of Interference Events over 10-day sim period	Avg Duration of Interference Event (min)	Max Interference Event Duration (min)
TRIG (Lost Lock; C/A & P1 & P2)	**-67.000**	0.000	0.000	0.000	0.000
	-68.000	0.000	0.000	0.000	0.000
	-69.000	0.000	0.000	0.000	0.000
	-70.000	0.000	0.000	0.000	0.000
	-71.000	0.000	0.000	0.000	0.000
	-72.000	0.147	15.000	1.407	2.383
TRIG (5 dB; P1)	**-73.000**	0.493	60.000	1.184	3.867
TRIG (5 dB; P2)	**-74.000**	1.107	55.000	2.899	7.283
TRIG (5 dB; C/A)	**-75.000**	1.793	103.000	2.507	8.083
	-76.000	2.389	105.000	3.276	9.217
TRIG (3 dB; P2)	**-77.000**	3.050	122.000	3.600	9.617
TRIG (3 dB; C/A) TRIG (1 dB; P2)	**-78.000**	3.529	89.000	5.710	10.633
	-79.000	3.927	100.000	5.655	10.850
TRIG (3 dB; P1)	**-80.000**	4.247	94.000	6.506	11.100
	-81.000	4.539	96.000	6.809	11.367
TRIG (1 dB; C/A & P1)	**-82.000**	4.790	92.000	7.497	11.633
	-83.000	5.062	118.000	6.177	11.967
	-84.000	5.361	104.000	7.423	12.183
	-85.000	5.609	104.000	7.767	13.000
	-300.000	11.515	167.000	9.929	21.450

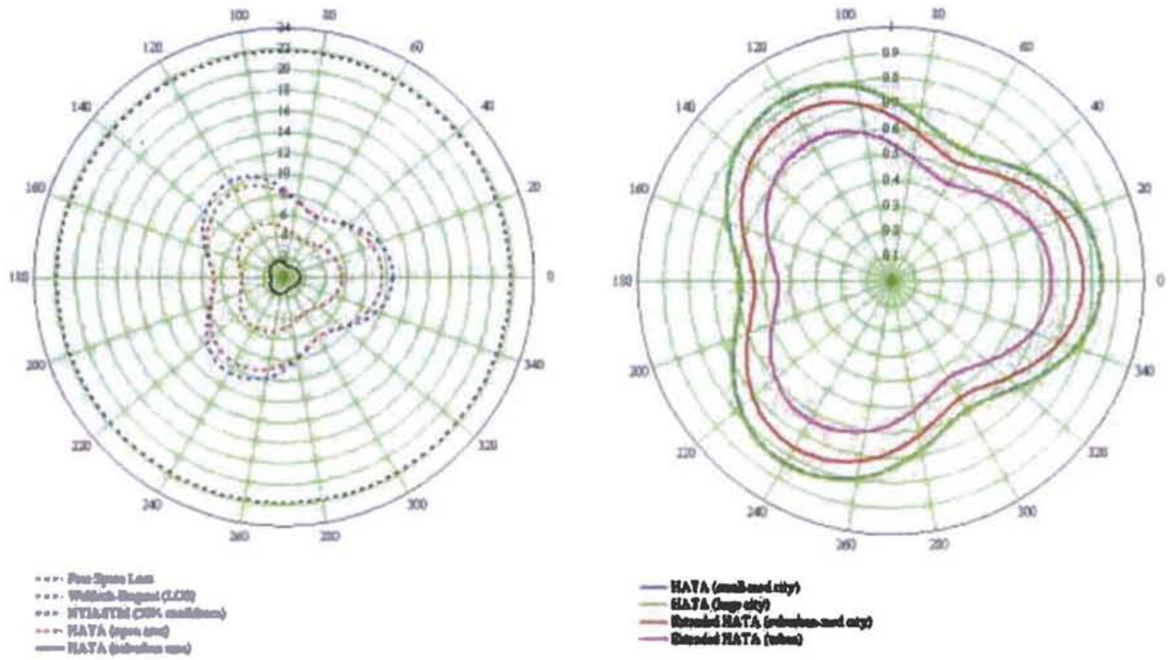

Figure 6-10. Separation Distance Contours for TRIG and Interference Threshold = -82 dBm (1 dB C/No degradation)

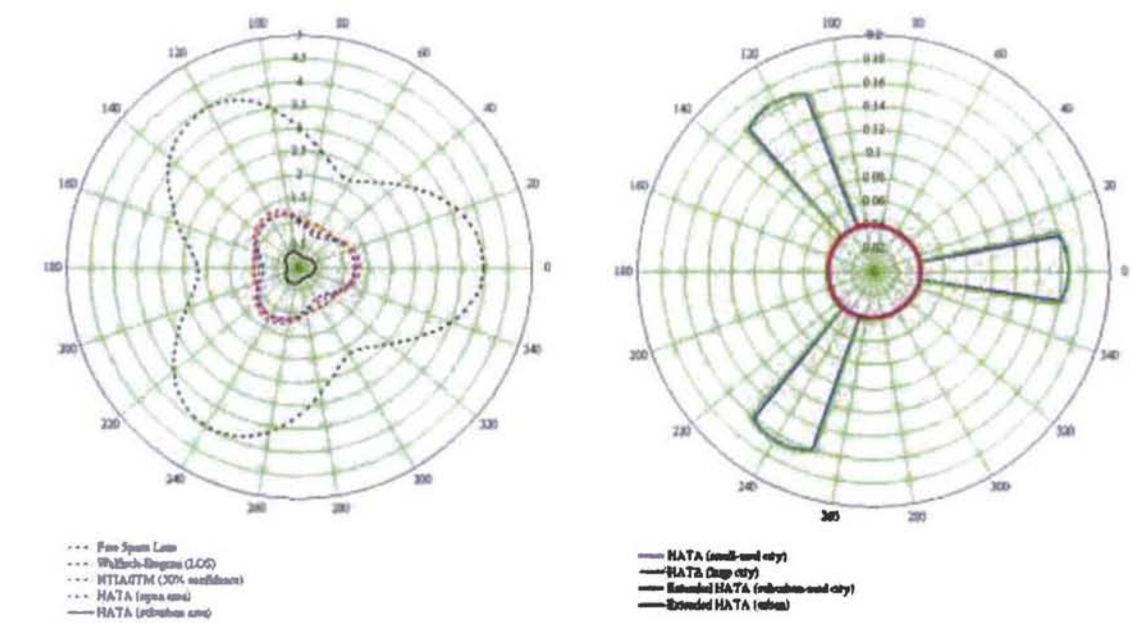

Figure 6-11. Separation Distance Contours for IGOR and Interference Threshold = -57 dBm (1 dB C/No degradation)

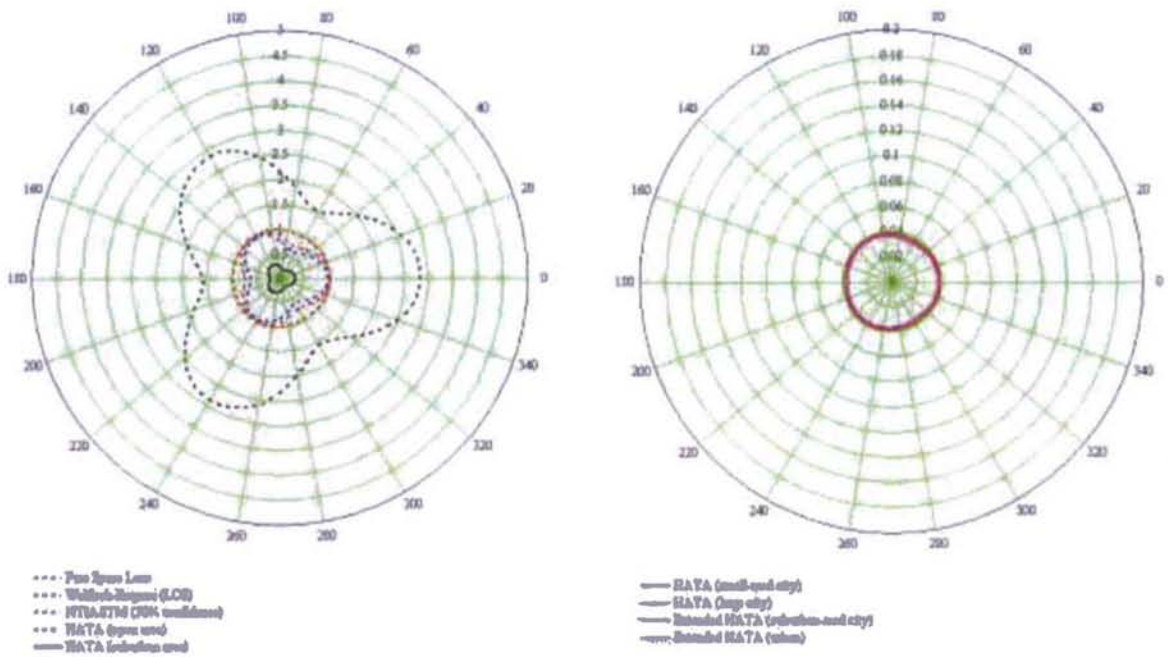

Figure 6-12. Separation Distance Contours for Receiver #15 and Interference Threshold = -54 dBm (1 dB C/No degradation)

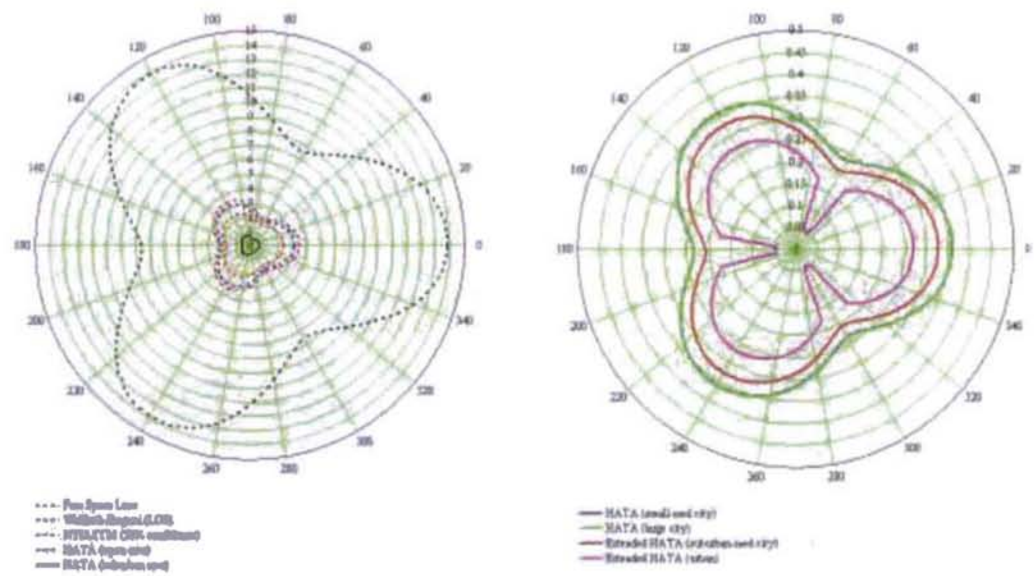

Figure 6-13. Separation Distance Contours for Receiver #16 and Interference Threshold = -68 dBm (1 dB C/No degradation)

Table 6-11. Exclusion Areas for LightSquared Las Vegas Deployment for Different Propagation Models

Note: Values are total area in which interference exceeds the 1 dB C/No degradation thresholds (-56/-68 dBm) for Receivers #15 & #16

Propagation Model	Rx #15 1 dB C/No degradation threshold	Rx #16 1 dB C/No degradation threshold
	-56 dBm	-68 dBm
Free-Space Loss	2008 km^2	3529 km^2
Walfisch-Ikegami (LOS)	532.1 km^2	1478 km^2
NTIA/ITM (50% confidence)	632 km^2	1420 km^2
Hata (open area)	424 km^2	1123 km^2
Hata (suburban)	32.4 km^2	154.8 km^2
Hata (small-med city)	5.3 km^2	34.9 km^2
Hata (large city)	5.3 km^2	34 km^2
Extended Hata (suburban-med city)	4 km^2	28.1 km^2
Extended Hata (urban)	2.6 km^2	18.3 km^2

FAA Simulation

Impact of LightSquared Emissions on Aviation

Following charts show impact for the LightSquared planned initial deployment of terrestrial base stations.

Assumptions

- Effective isotropic radiated power (EIRP) of 62 dBm/sector
  - Based upon LightSquared's stated plans
  - Importantly, the FCC has authorized 10× higher EIRPs
- Base station antenna gain patterns provided by LightSquared
- Free-space propagation modeling

What LightSquared Received Power Levels are Harmful?

FAA TSOs and ICAO SARPs both require that avionics meet all performance requirements for interference levels less than -86.4 dBm* at the LightSquared upper frequency of 1552.7 MHz

- Only require that avionics do not output hazardously misleading information with interference beyond this level

Avionics tests

- Initial testing conducted, more rigorous testing underway
- Small sample size: ~half-dozen certified receiver models owned by FAA (vs many dozen models fielded)
- Least robust receiver to LightSquared emissions based upon initial tests was Receiver #2 – significant degradation at -64 dBm and failure to produce a position output at -47 dBm
- The popular Receiver #3 began to degrade at -54 dBm and failed to produce a position output at -37 dBm

*All power levels mentioned in this subtask report are referenced to the output port of the passive airborne antenna element

Analysis Approach

For a grid of latitude/longitudes at each stated altitude, the total power received from all visible LightSquared base stations was computed:

- Base station patterns on following chart
- Airborne GPS antenna gain pattern shown on subsequent chart
- Free space path loss
- 4/3-Earth radius model used to determine visibility
- 0.5 degree grid used for CONUS-level charts

Contours depict where total received interference exceeds either maximum tolerable level from avionics standards or a level determined to cause degradation from initial characterization testing.

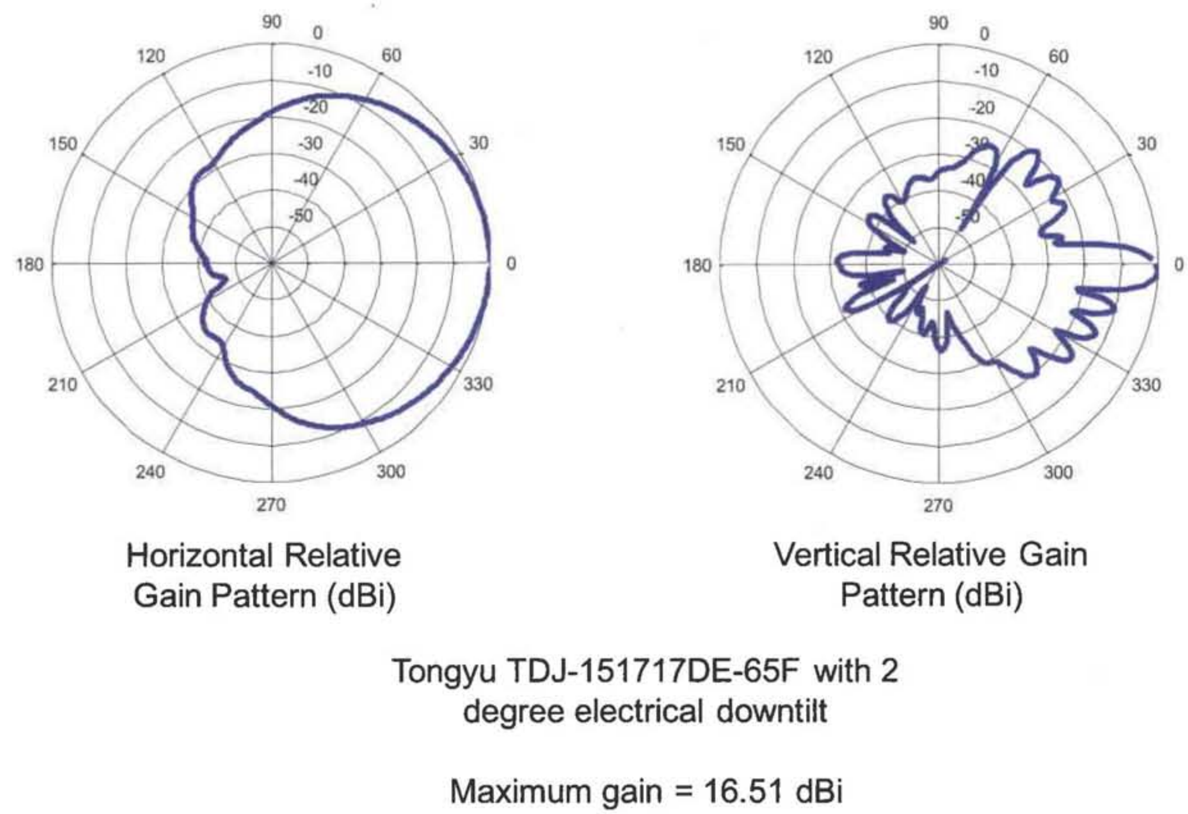

Figure 6-14. Base Station Gain Patterns

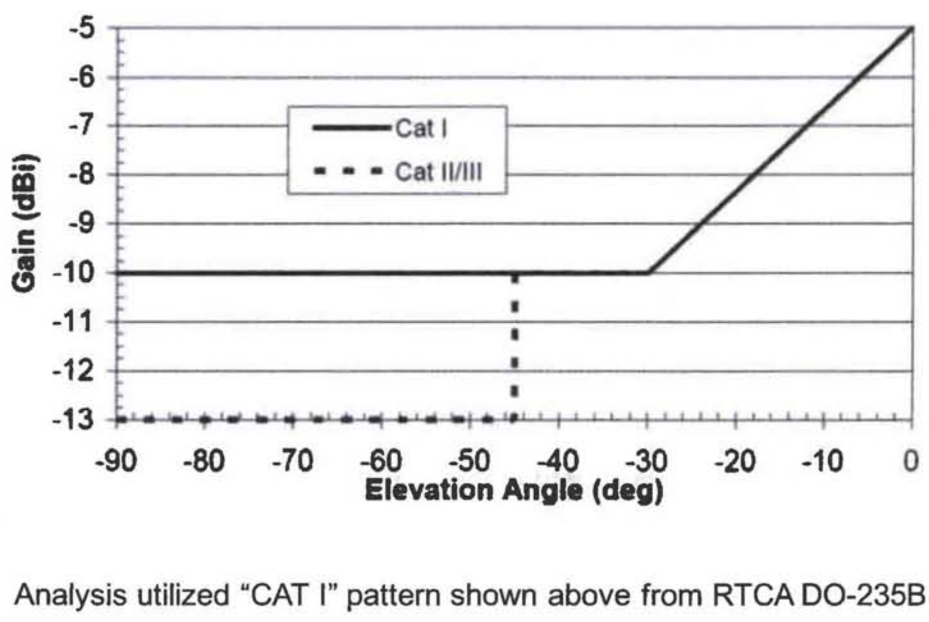

Figure 6-15. Airborne Antenna Gain Pattern

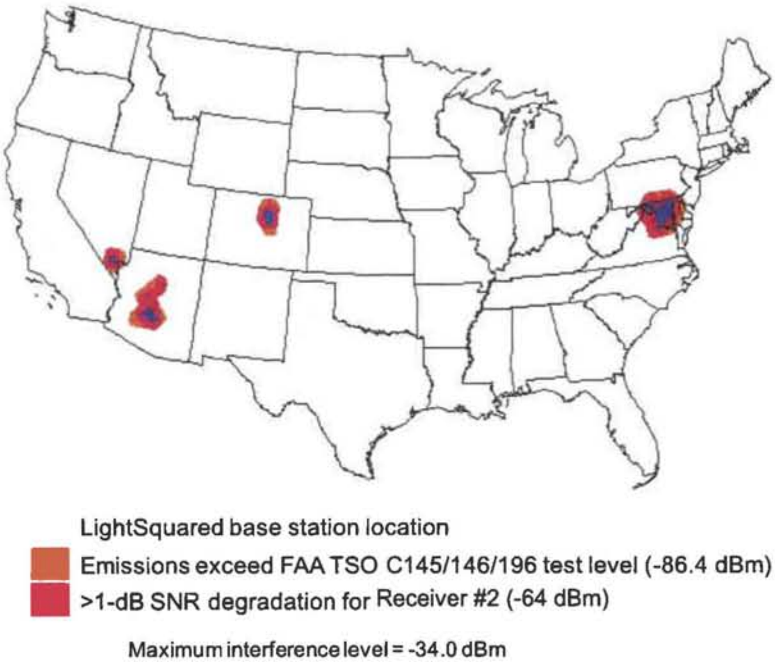

Figure 6-16. Initial LightSquared Deployment (2391 of 40000+ Towers)
Aircraft at 200'

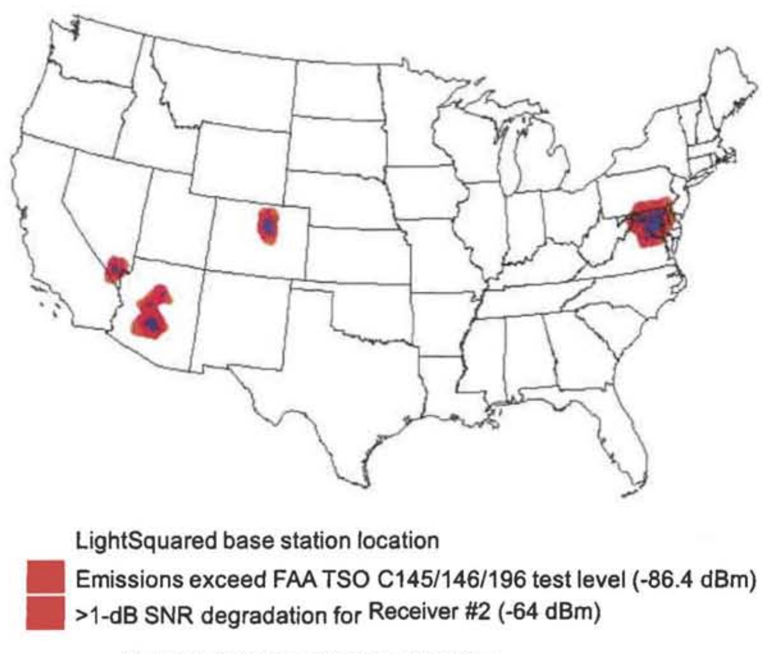

Figure 6-17. Initial LightSquared Deployment (2391 of 40000+ Towers)
Aircraft at 250'

Figure 6-18. Initial LightSquared Deployment (2391 of 40000+ Towers)
Aircraft at 350'

Figure 6-19. Initial LightSquared Deployment (2391 of 40000+ Towers)
Aircraft at 400'